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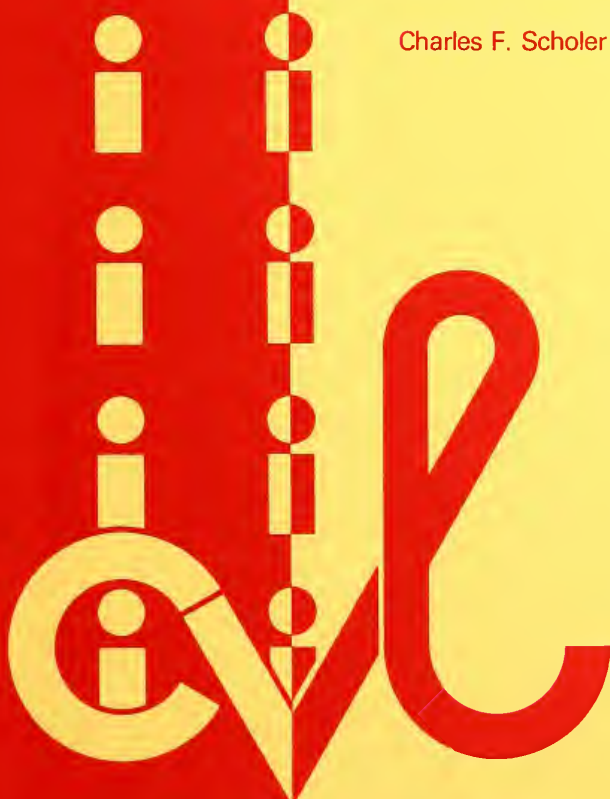


JOINT HIGHWAY RESEARCH PROJECT

JHRP-75-21

THE INFLUENCES OF RETARDING
ADMIXTURES ON VOLUME CHANGES
OF CONCRETE

Charles F. Scholer



PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

Final Report

THE INFLUENCES OF RETARDING ADMIXTURES ON VOLUME CHANGES OF CONCRETE

TO: J. F. McLaughlin, Director
Joint Highway Research Project

October 1, 1975

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-56N

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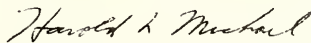
Attached is the Final Report on the HPR Part II Research Study titled "The Influence of Retarding Admixtures on Volume Changes of Concrete". This is a summary report authored by Professor C. F. Scholer. Prof. W. L. Dolch was a co-principal investigator on the project.

This report summarizes the findings of three previous interim reports. For the reader interested in the detailed methods, and findings, they should study the appropriate interim report.

Of general interest to all concerned with concrete is the evidence which emphasizes the necessity of adequate curing for concrete containing retarding admixtures. Normal curing procedures are sufficient but their absence or late application will aggravate shrinkage problems to a greater extent on concrete with retarders than on plain concrete.

This report is submitted for acceptance as fulfillment of the objectives of this research. It will also be forwarded for review, comment and similar acceptance to the ISHC and the FHWA

Respectfully submitted



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16. Abstract <p>A study of 65 different chemical compounds and of three different ASTM Type D admixtures on the characteristics of cement pastes in both fresh and hardened conditions. Setting times, molecular configuration related to the effectiveness of the retarders, oven dry shrinkage, non-evaporable water and the specific surface area were determined for these "admixtures".</p> <p>Concrete specimens were prepared to evaluate the long-term drying shrinkage of the proprietary admixtures which had been evaluated as pastes. Long term shrinkage of concrete was not appreciably affected by the admixtures tested.</p> <p>Plastic drying shrinkage of paste was evaluated from the completion of mixing until approximately initial set. The proprietary varieties of admixtures were used in this investigation. The amount of plastic shrinkage varied with the variety of admixture and an interaction was found between admixture variety and drying condition (humidity).</p>			
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Final Report

THE INFLUENCE OF RETARDING ADMIXTURES.
ON VOLUME CHANGES OF CONCRETE

by

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Project No: C-36-47L

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Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station
Purdue University

in cooperation with the

Indiana State Highway Commission

and the

U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Purdue University
West Lafayette, Indiana
October 1, 1975

Final Summary Report

THE INFLUENCE OF RETARDING ADMIXTURES ON VOLUME CHANGES OF CONCRETE

I. BACKGROUND SUMMARY

A. State of the Art

A retarding admixture is "a material other than water, aggregates, and hydraulic cement, used as an ingredient of concrete or mortar, and added to the batch immediately before or during its mixing"* which delays the setting of cement paste and likewise a concrete. These admixtures frequently will allow a reduction in water content necessary to obtain a given slump. The most commonly used admixtures for retarding concrete in Indiana are ASTM Type D, water-reducing and retarding admixtures. These generally result in an improved compressive strength and some reduction in permeability; hence durability under freezing and thawing conditions is improved. The only disadvantages of Type D admixtures are a greater rate of slump loss, which can be a problem if the concrete is warm and the time before placement is large, and increased drying shrinkage. Drying shrinkage is a form of volume change, the primary form studied in this investigation.

The plan of study for this project stated "The use of retarders enters the drying shrinkage picture from two sides. First, by definition, a retarder delays the set; thus it allows evaporation to occur without creating shrinkage stresses in the concrete, since it has a more-or-less plastic condition. One could expect a reduction in shrinkage cracks if

* American Concrete Institute, Cement and Concrete Terminology, Publication SP-19, 1967.

the greatest portion of water loss, i.e., potential drying shrinkage, occurs at this time.

On the other side of the picture, retarders delay the early development of strength; thus when concrete has set it may not have sufficient strength to resist subsequent shrinkage stress and cracks may form. This situation is, of course, not critical if little shrinkage occurs at this stage."

B. Importance of retarders.

The increased setting time for retarders is an advantage on many construction situations especially those with a continuous superstructure over one or more piers. The Indiana State Highway Commission requires their use in these circumstances and allows their use in others. Warm temperatures accelerate the setting of concrete and this is often desirably counteracted by the use of retarders. Many times the use of an ASTM type D admixture will be of benefit to both the constructor and the owner for reasons of the delayed set and/or the water reduction. The use of these admixtures is now routine and will probably grow in the coming years. Consideration of such material for paving concrete has and will occur.

C. Interim reports.

Three separate interim reports have been made on this research project. The first was by far the largest and represented the primary effort. It was "Retarders for Concrete, and Their Effects on Setting Time and Shrinkage," JHRP Report No. 72-51 by Yasuhiko Yamamoto under

direction of Prof. W. L. Dolch. It considered in great detail the effect of various chemicals on the time of set and shrinkage of cement paste. It also considered the mechanisms by which retarders work. Many chemicals were investigated but included were the three common generic classifications of set retarding admixtures, the carbohydrate type, the hydroxycarboxylic acid type and the calcium lignosulfonate type. These represent nearly all of the material used for such purposes in the United States and all of the material approved for use by the Indiana State Highway Commission.

The second interim report, "Effects of Retarding Admixtures on Plastic Shrinkage of Portland Cement Paste," JHRP Report No. 73-20 by Hanume Gowda under the direction of Prof. C. F. Scholer, dealt with the three common generic types of admixtures and how their plastic drying shrinkages were affected by different drying rates (humidity, wind and temperature). Plastic drying shrinkage occurs while the concrete is plastic hence, prior to set. Unusual methods of measurement were required for this phase.

A third interim report was JHRP Report 74-13, "The Influence of Retarding Admixture on the Drying Shrinkage of Concrete" by Professor W. L. Dolch and C. F. Scholer. This report gave the drying shrinkage results on concrete whereas the other drying shrinkage results were on the drying shrinkage of small paste samples. The three commonly available types of retarders were given the greatest attention in the concrete tests.

II. OBJECTIVES OF THIS INVESTIGATION

The effects retarding admixtures have on volume changes of concrete was not fully understood hence an improved understanding was a major objective of this investigation.

A further objective was to identify those material and/or methods which would minimize volume changes i.e., shrinkage.

A. Effect of retarder on volume change.

The characterization of the basic compounds common to retarding admixtures with respect to their influence on concrete paste structure and resulting volume changes offered the possibility of identifying the better admixtures for particular conditions and needs.

Another objective was to determine if the shrinkage of retarded concrete in early ages occurs to a greater or lesser extent in the plastic or hardened stages.

B. Reasons for the influence of the admixture.

The many different compounds characterized were selected so as to allow interpretation of the results with the hope that the reasons for the resulting behavior of the paste might be better understood.

C. Recommended material.

The commercially available materials were studied because of their practical significance on construction. This included concrete specimens subjected to long term drying and a study of the plastic shrinkage of

pastes, with an appropriate amount of admixture, exposed to varying conditions while in the plastic state.

III. SUMMARY OF THE INVESTIGATIONS

A. Effectiveness of Retarders, Molecular Influence and Shrinkage of Concrete Paste.

1. Time of set tests.

The setting time for concrete is influenced by many different chemicals and a total of sixty-five selected chemicals were used to examine the effects of the molecular structure of the chemicals on setting time. A list of the chemicals used is given in Table 1.

The effects of these chemicals on setting time was evaluated by ASTM standard test method C-403, "Time of Setting of Concrete Mixtures by Penetration Resistance" using Ottawa sand mortar. The results of the tests allow a comparison of penetration resistance with elapsed time. Initial set is defined as the elapsed time after water is added to cement for a penetration resistance of 500 psi to be developed. Final set is defined as 4000 psi penetration resistance. A typical set of results are those shown in Figure 1 in which the effect of various admixture concentrations are plotted.

Table 2 lists the measured initial setting time, T500, of the various chemicals tested. The ratio T500/T50 expressed the relative time for 500 psi penetration to 50 psi penetration values and indicated when the chemicals accelerated the very

Table 1 - List of Chemicals

Name	Chemical Formula	Company
Malonic Acid	$\text{CO}_2\text{HCH}_2\text{CO}_2\text{H}$	Eastman
Succinic Acid	$\text{CO}_2\text{H}(\text{CH}_2)_2\text{CO}_2\text{H}$	Allied Chem.
Glutaric Acid	$\text{CO}_2\text{H}(\text{CH}_2)_3\text{CO}_2\text{H}$	Eastman
Adipic Acid	$\text{CO}_2\text{H}(\text{CH}_2)_4\text{CO}_2\text{H}$	Fisher
Glycolic Acid	$\text{CO}_2\text{HCH}_2\text{OH}$	Fisher
Glycine	$\text{CO}_2\text{HCH}_2\text{NH}_2$	M.C. & B.
Mercaptoacetic Acid (liq.)	$\text{CO}_2\text{HCH}_2\text{SH}$	M.C. & B.
Monochloroacetic Acid	$\text{CO}_2\text{HCH}_2\text{Cl}$	Mallinckrodt
Glyoxylic Acid (Hydrate)	$\text{CO}_2\text{HCHO}\cdot\text{xH}_2\text{O}$	Aldrich
Pyruvic Acid (liq.)	$\text{CO}_2\text{HCOCH}_3$	M.C. & B.
Lactic Acid (85% liq.)	$\text{CO}_2\text{HCHOHCH}_3$	Mallinckrodt
α -Hydroxy-N-Butyric Acid (liq.)	$\text{CO}_2\text{HCHOHCH}_2\text{CH}_3$	K & K
Ketomalonic Acid (Disodium)	$\text{CO}_2\text{NaCOCO}_2\text{Na}$	Aldrich
Tartronic Acid	$\text{CO}_2\text{HCHOHCO}_2\text{H}$	Aldrich
(-) Malic Acid	$\text{CO}_2\text{HCHOHCH}_2\text{CO}_2\text{H}$	J. T. Baker

Table 1, cont.

Name	Chemical Formula	Company
(d) - Tartaric Acid	$\text{CO}_2\text{H}(\text{CHOH})_2\text{CO}_2\text{H}$	Mallinckrodt
Dihydroxymaleic Acid	$\text{CO}_2\text{H}(\text{COH})_2\text{CO}_2\text{H}$	Aldrich
Dihydroxytartaric Acid	$\text{CO}_2\text{H}(\text{C}(\text{OH})_2)_2\text{CO}_2\text{H}$	Aldrich
3-Hydroxypropionic Acid	$\text{CO}_2\text{HCH}_2\text{CH}_2\text{OH}$	Aldrich
Mucic Acid	$\text{CO}_2\text{H}(\text{CHOH})_4\text{CO}_2\text{H}$	Aldrich
Gluconic Acid (50% liq.)	$\text{CO}_2\text{H}(\text{CHOH})_4\text{CH}_2\text{OH}$	Eastman
2-Ketoglutaric Acid	$\text{CO}_2\text{H}(\text{CH}_2)_2\text{COCO}_2\text{H}$	Aldrich
1,2,3-Propanetricarboxylic Acid	$\text{CO}_2\text{HCH}_2\text{CH}(\text{CO}_2\text{H})\text{CH}_2\text{CO}_2\text{H}$	Eastman
Citric Acid	$\text{CO}_2\text{HCH}_2\text{C}(\text{OH})(\text{CO}_2\text{H})\text{CH}_2\text{CO}_2\text{H}$	Mallinckrodt
Crotonic Acid	$\text{CH}_3\text{CH}:\text{CHCO}_2\text{H}$	M.C. & B.
Acetaldol (liq.)	$\text{CH}_3\text{CHOHCH}_2\text{CHO}$	Aldrich
Methyl Glycolate (liq.)	$\text{CH}_3\text{OCOCH}_2\text{OH}$	K & K
α -Hydroxyacetamide	$\text{NH}_2\text{COCH}_2\text{OH}$	K & K
1,3-Dihydroxy-2-Propanone	$\text{CH}_2\text{OHCOCH}_2\text{OH}$	Eastman
Glycerin (liq.)	$\text{CH}_2\text{OHCHOHCH}_2\text{OH}$	Fisher
3-Hydroxy-2-Butanone (liq.)	$\text{CH}_3\text{COCHOHCH}_3$	Eastman

Table 1, cont.

Name	Chemical Formula	Company
N-Methylpropionamide (liq.)	$\text{CH}_3\text{CH}_2\text{CONHCH}_3$	Eastman
Ethyl Acetoacetate (liq.)	$\text{CH}_3\text{COCH}_2\text{COOCH}_2\text{CH}_3$	M.C. & B.
Allyl Alcohol (liq.)	$\text{CH}_2=\text{CHCH}_2\text{OH}$	Fisher
2-Butene-1,4-Diol (liq.)	$\text{CH}_2\text{OHCH}:\text{CHCH}_2\text{OH}$	Aldrich
Chloral Hydrate	$\text{C}(\text{Cl})_3\text{CH}(\text{OH})_2$	Aldrich
Pentaerythritol	$\text{C}(\text{CH}_2\text{OH})_4$	Eastman
2,4 - Pentanedione (liq.)	$\text{CH}_3\text{COCH}_2\text{COCH}_3$	M.C. & B.
Sucrose	$\text{C}_6\text{H}_{11}\text{O}_5-\text{O}-\text{C}_6\text{H}_{11}\text{O}_5$	Baker
Resorcinol	$\text{m}-\text{C}_6\text{H}_4(\text{OH})_2$	Eastman
Catechol	$\text{o}-\text{C}_6\text{H}_4(\text{OH})_2$	M.C. & B.
Hydroquinone	$\text{p}-\text{C}_6\text{H}_4(\text{OH})_2$	Fisher
m-Nitrophenol	$\text{m}-\text{NO}_2\text{C}_6\text{H}_4\text{OH}$	Baker
o-Nitrophenol	$\text{o}-\text{NO}_2\text{C}_6\text{H}_4\text{OH}$	M.C. & B.
p-Nitrophenol	$\text{p}-\text{NO}_2\text{C}_6\text{H}_4\text{OH}$	M.C. & B.
m-Hydroxybenzoic Acid	$\text{m}-\text{HO}\cdot\text{C}_6\text{H}_4\text{CO}_2\text{H}$	Aldrich

Table 1, cont.

Name	Chemical Formula	Company
Salicylic Acid	$\text{o-HO} \cdot \text{C}_6\text{H}_4\text{CO}_2\text{H}$	Baker
p-Hydroxybenzoic Acid	$\text{p-HO} \cdot \text{C}_6\text{H}_4 \cdot \text{CO}_2\text{H}$	Eastman
Benzoic Acid	$\text{C}_6\text{H}_5\text{CO}_2\text{H}$	Baker
Benzyl Alcohol (liq.)	$\text{C}_6\text{H}_5\text{CH}_2\text{OH}$	Baker
DL-Mandelic Acid	$\text{C}_6\text{H}_5\text{CH(OH)CO}_2\text{H}$	Aldrich
o-Hydroxyacetophenone (liq.)	$\text{HOC}_6\text{H}_4\text{COCH}_3$	Aldrich
Picric Acid	$2,4,6-(\text{NO}_2)_3 \cdot \text{C}_6\text{H}_2\text{OH}$	Baker
Pyrogallol	$1,2,3-(\text{HO})_3 \cdot \text{C}_6\text{H}_3$	Fischer
Phloroglucinol	$1,3,5-(\text{HO})_3 \cdot \text{C}_6\text{H}_3 \cdot 2\text{H}_2\text{O}$	M.C. & B.
Gallic Acid	$3,4,5-(\text{HO})_3 \cdot \text{C}_6\text{H}_2\text{CO}_2\text{H}$	Eastman
2,4,6-Trihydroxybenzoic Acid (Monohydrate)	$2,4,6-(\text{HO})_3 \cdot \text{C}_6\text{H}_2\text{CO}_2\text{H} \cdot \text{H}_2\text{O}$	Aldrich
EDTA (Disodium)	*	Mallinckrodt
Nitritotriacetic Acid (Disodium)	$\text{HOCOCH}_2\text{N}(\text{CH}_2\text{COONa})_2$	Eastman

* $(\text{CH}_2\text{CO}_2\text{H})(\text{CH}_2\text{CO}_2\text{Na})\text{N}(\text{CH}_2)_2\text{N}(\text{CH}_2\text{CO}_2\text{Na})(\text{CH}_2\text{CO}_2\text{H})$

Table 1, cont.

Name	Chemical Formula	Company
Dye 27195	-----	----
Dye 25380	-----	----
Dye 24410	-----	----
Dye 42755	-----	----
Eriochrome Black T	-----	Fisher
Calcium Lignosulfonate	-----	----

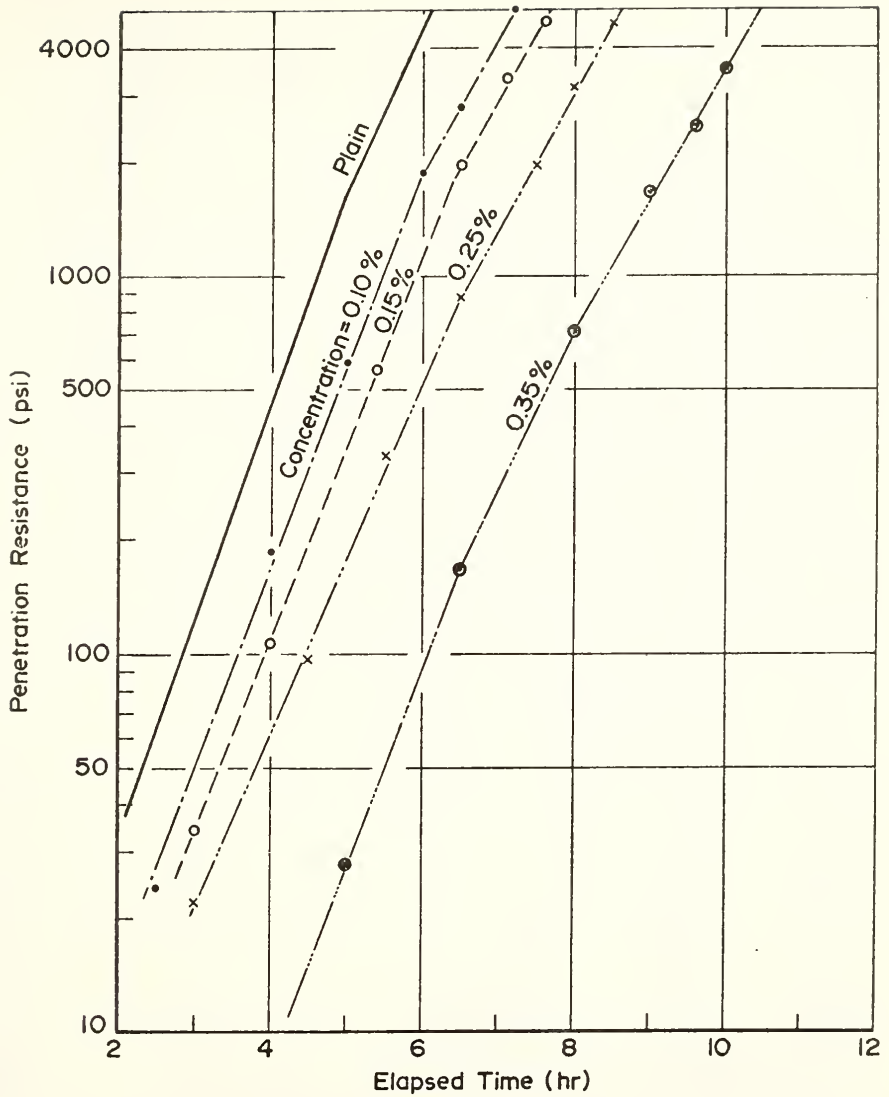


Figure 1 Penetration Resistance vs Elapsed Time for Mortar with Retarder Calcium Lignosulfonate

Table 2 Summary of Relative Initial Setting Time of Mortars When Pure Chemicals Were Added

Chemical	Concentration of Chemical			
	0.1%		0.5%	
	T500	T500/T50	T500	T500/T50
Malonic Acid	102	0.93	145	0.90
Succinic Acid	110	1.05	137	1.12
Glutaric Acid	110	1.00	100	0.97
Adipic Acid	101	0.97	-	-
Glycolic Acid	128	0.94	*	2.45**
Glycine	100	1.00	96	0.97
Mercaptoacetic Acid	113	1.00	128	0.91
Monochloroacetic Acid	-	-	108	1.02
Glyoxylic Acid (Hydrate)	127	1.04	-	-
Pyruvic Acid	207	1.06	-	-
Lactic Acid	102	1.00	118	0.96
α -Hydroxy-N-Butyric Acid	100	1.02	-	-
Ketomalonic Acid (Disodium)	154	1.01	-	-
Tartronic Acid	278	2.32	-	-
(-) Malic Acid	198	1.01	-	-

* Retardation was too large to determine in the limit of the experiment.

** T100/T50 instead of T500/T50.

early hydration of cement. The larger the ratio the more these early reactions were accelerated. Strong retarders such as tartronic acid, citric acid and sucrose have large values of T500/T50.

2. Shrinkage tests of cement pastes.

Small test specimens of cement paste at a 0.40 water:cement ratio were fabricated for shrinkage tests. These specimens were 0.20 inches square and 4 inches long with "ball point pen tip" studs embedded in the paste specimen. The small size specimens were desirable in order to reduce drying time and to minimize humidity variations through the specimen. Specimens were stored in saturated calcium hydroxide solution until they reached the desired age for drying.

Drying was accomplished in a vacuum oven controlled to a temperature of 105 to 110°C. This severe drying was used to eliminate carbonation and to reduce the length of the test. After cooling in a controlled atmosphere to prevent either carbonation or water gain, specimens were measured for length and weight.

3. Non-evaporable water determination.

The middle third of shrinkage specimens were used for determination of non-evaporable water by a loss on ignition test. Non-evaporable water was defined as water remaining in a sample during vacuum oven drying of 24 hours at 110°C and lost on drying at about 1050°C. Error due to partial carbonation of the cement could occur but was believed to be negligible.

4. Results of these tests are shown in Figures 2 through 6.

Figures 2 and 3 show the measured shrinkage of the paste specimen at 20 through 90 percent degree of hydration. Note that differences are most pronounced below 40 percent degree of hydration. Figures 4, 5 and 6 shows the relationship between degree of hydration and values of specific surface determined by the water vapor adsorption methods. It should be noted that different admixtures cause different results indicating that they do affect the microstructures of the paste, but in a relatively small way, i.e., most values range between 175 and 240 m^2/g .

5. Conclusions of the investigation on Effectiveness of Retarders, Molecular Influence and Shrinkage of Concrete Paste.

1. Strong retarders have a molecular composition that includes many oxygen atoms constrained to approach each other closely. Hydroxyl, carboxyl, and carbonyl are all effective, and carbonyl seems especially strong in its influence. Many α -hydroxy acids are retarders, but the presence of other groups can exert a strong effect reducing the retarding action. The oxygen-containing groups can be presumed to exert polarizing influence that could contribute to relatively strong adsorption onto the solid surfaces of concern.

2. More weakly electronegative atoms on the molecule do not have the same effect as oxygens.

3. When cement pastes are strongly dried of all their evaporable water, they exhibit shrinkage behavior that shows a minimum at about half hydration and an earlier maximum. This

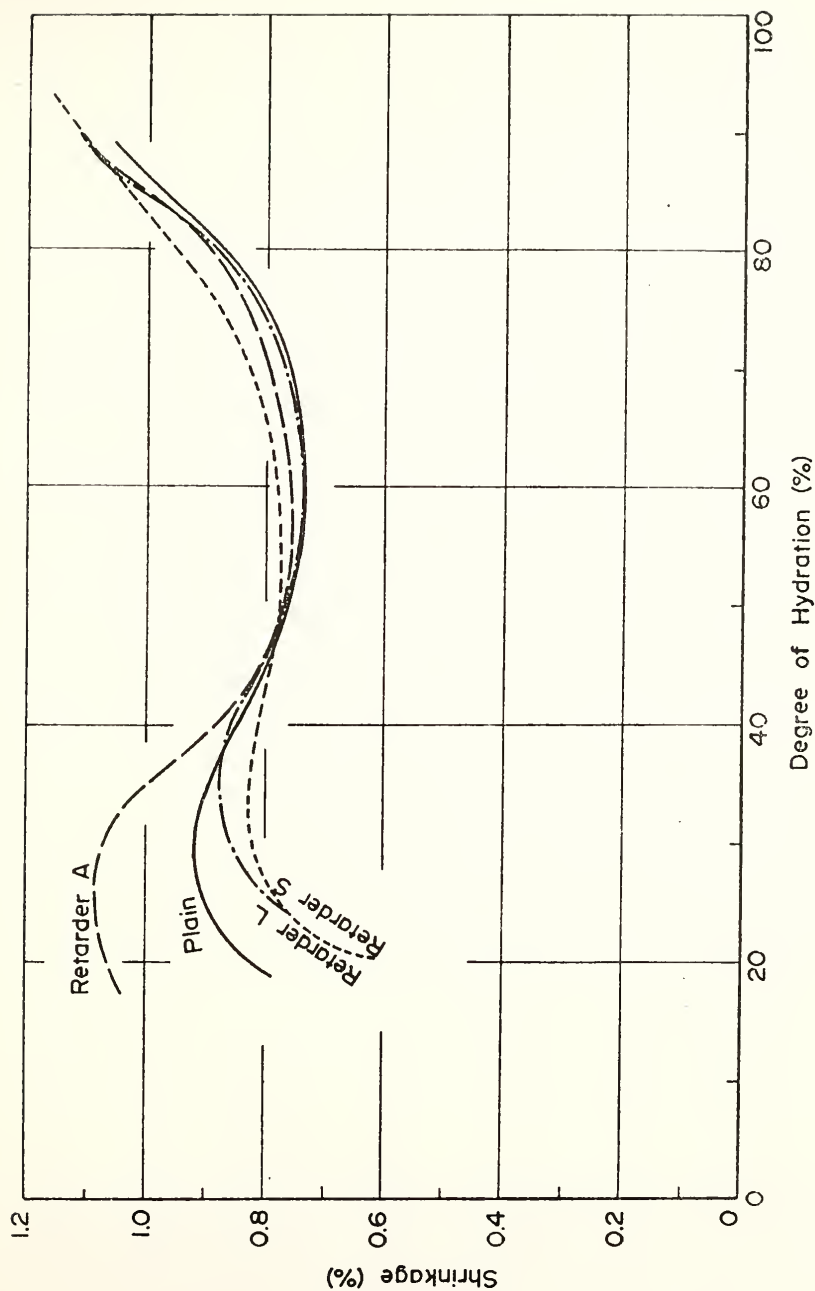


Figure 2 - Shrinkage of Vacuum Oven-Dried Cement Pastes at Various Stages of Hydration (Commercial Retarders)
 L - Calcium Lignosulfonate
 A - Hydroxycarboxylic Acid
 S - Carbohydrate (Sugar)

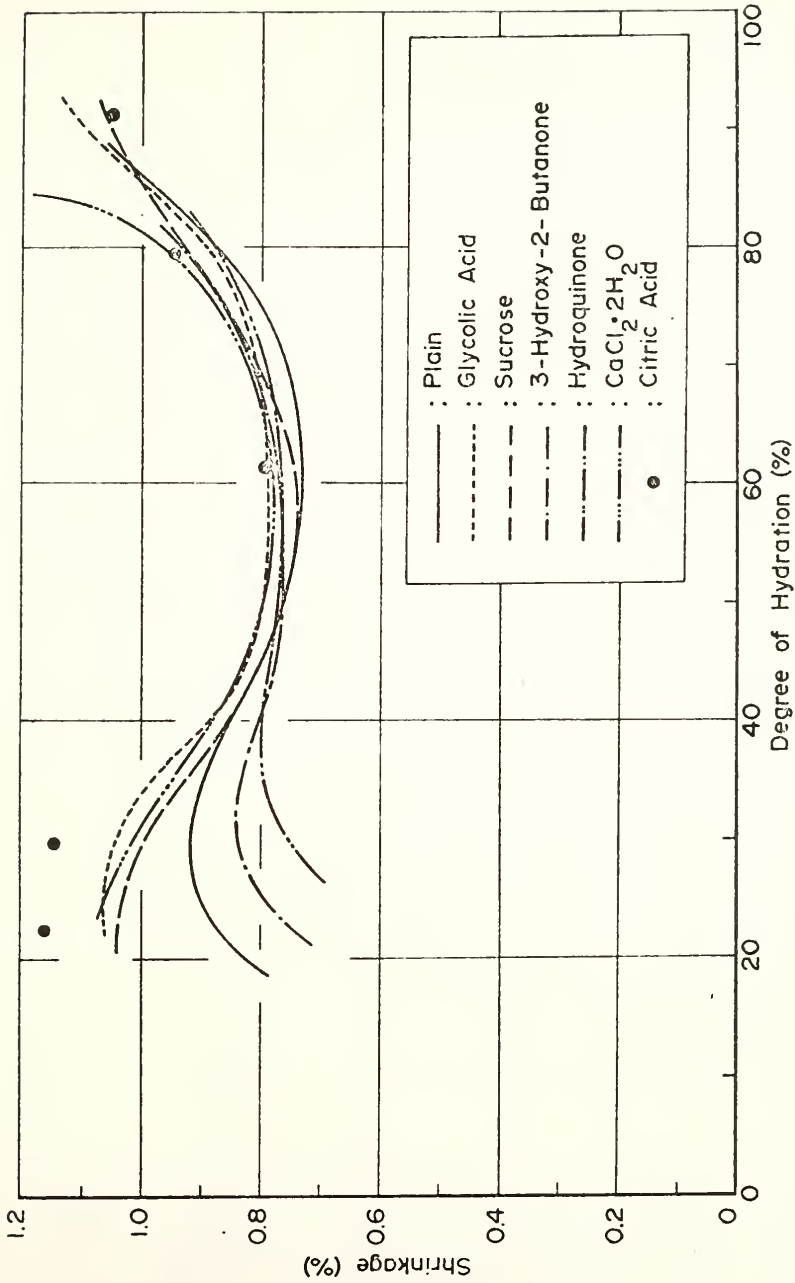


Figure 3 - Shrinkage of Vacuum Oven-Dried Cement Pastes at Various Stages of Hydration (Pure Chemicals)

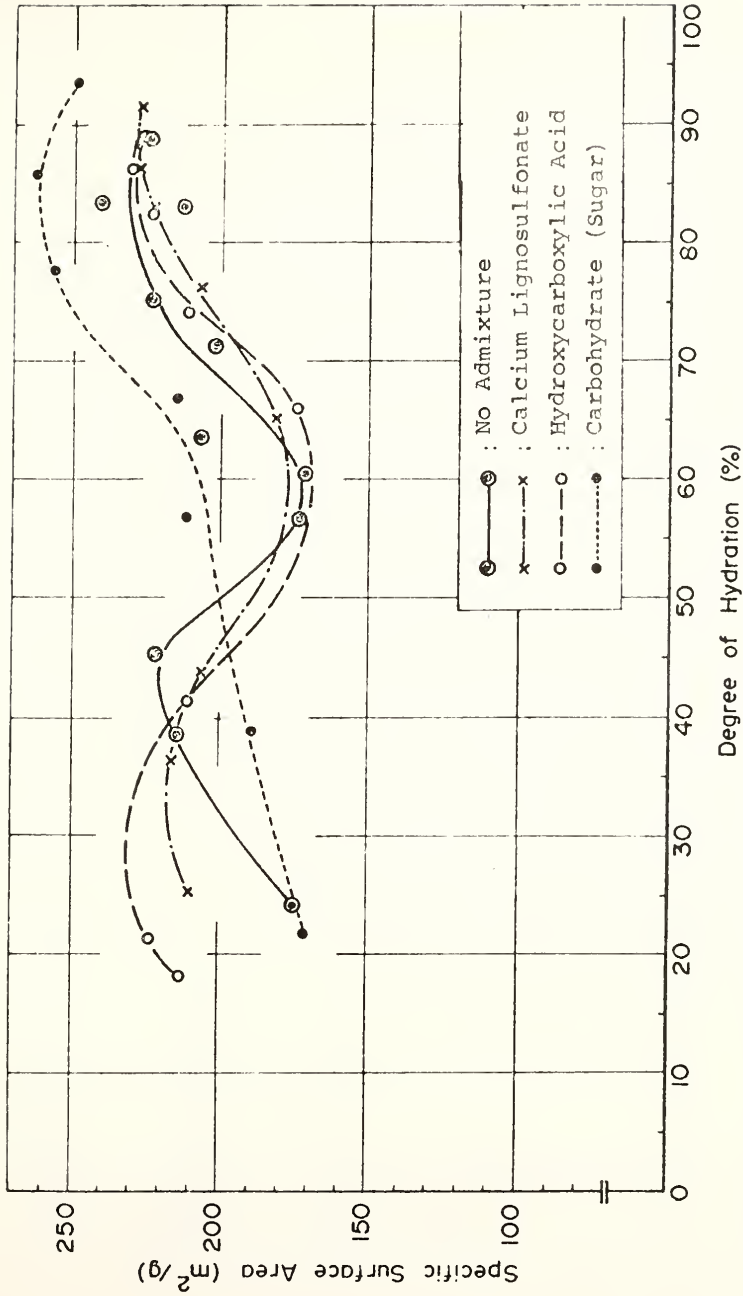


Figure 4 - Specific Surface Area of Hydrated Portion of Vacuum Oven-Dried Cement Pastes (Commercial Retarders)

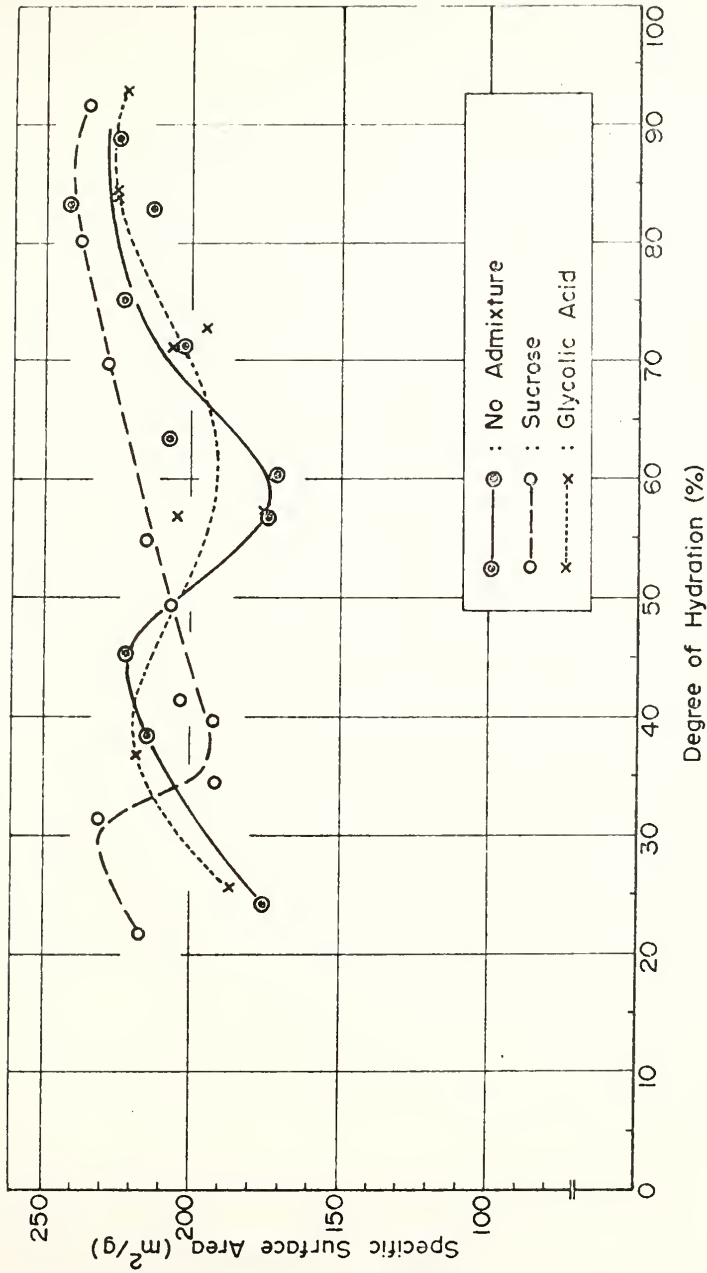


Figure 5 - Specific Surface Area of Hydrated Portion of Vacuum Oven-Dried Cement Pastes (Pure Chemicals - No. 1)

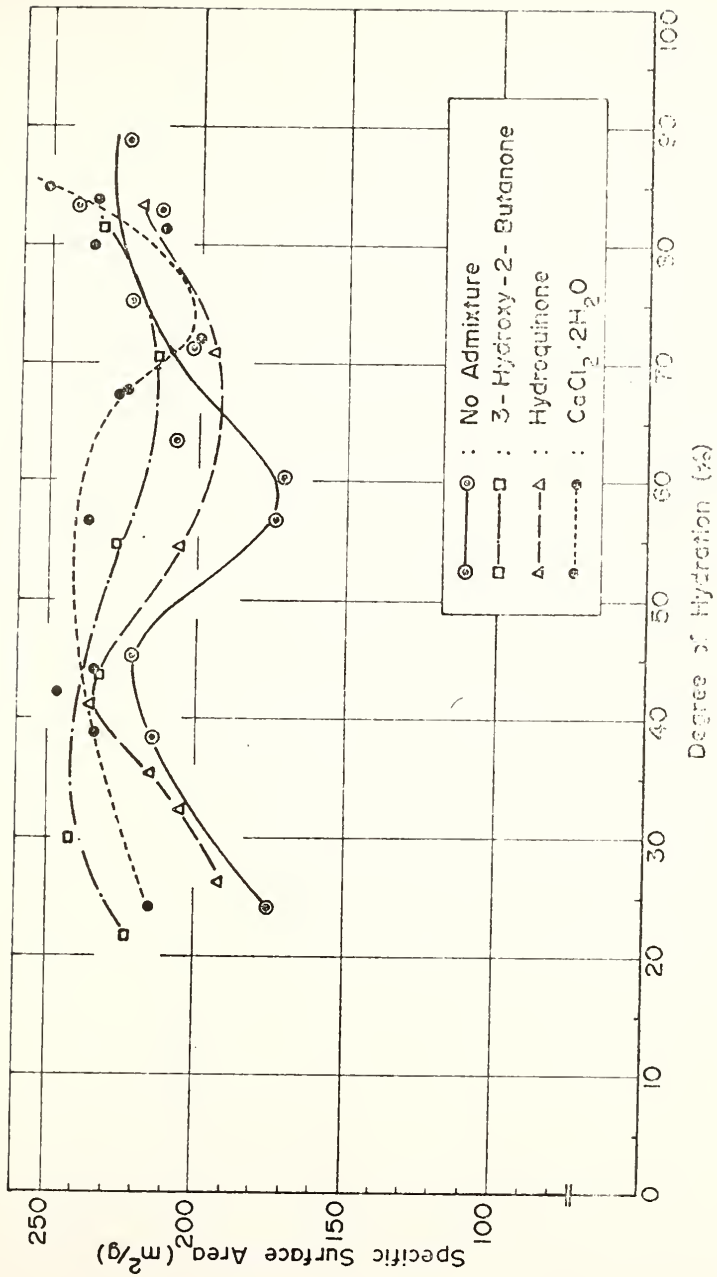


Figure 6 - Specific Surface Area of Hydrated Portion of Vacuum Oven-Dried Cement Pastes (Pure Chemicals - No. 2)

behavior is also exhibited by the change in specific surface area of the hydrated cement; the hydrate gains appreciable surface area between about 60% and 80% hydration, and thereafter remains relatively unchanged. Some cause and effect relationship exists between the specific surface area of a paste and its shrinkage potential, although other factors, such as restraint by unhydrated cement, are probably also operative.

4. Retarders cause a moderate increase in the shrinkage of cement pastes at ages greater than about half hydration. At lesser ages the shrinkage may be either increased or decreased.

5. The changes in shrinkage brought about by retarders can be partially ascribed to those brought about in specific surface areas of the hydrated cement, but other effects, probably related to the chemical species present, are also important.

B. Plastic Drying Shrinkage

1. Admixture and procedure used.

The three types of commercial admixtures evaluated in the work on drying shrinkage of paste were evaluated in a test to measure plastic drying shrinkage. This test, described in the interim report of August 1973, consisted of floating thin paste sections on mercury within a controlled atmosphere chamber. A magnetic proximeter was used to measure the length changes of the plastic paste on which a small steel target had been placed. This test procedure provided plastic shrinkage measurements which were very reproduceable. Humidity was controlled by bubbling

air through a sulfuric acid solution. This air passed from one end of the test chamber to the other. Three relative humidities were used, 25, 50 and 75 percent.

2. Results

Figures 7, 8 and 9 show the results of the plastic shrinkage tests. It should be noted that plastic shrinkage terminates when the specimen cracks which occurs when the paste specimen is no longer plastic. The visual difference in cracking of specimen made with different admixtures was striking, see Figure 10.

3. Conclusion of the plastic shrinkage tests.

Based upon the particular pastes investigated in this study the following conclusions were made.

1. Using retarding admixtures, plastic shrinkage is higher than the plastic shrinkage of plain paste. The higher shrinkage is due to the increased period of time spent in the plastic stage and, with some retarders, an increase in the amount of bleeding water.

2. The appearance of the first crack coincides with transition from a high initial rate of shrinkage to a slower rate. Since this transition approximately coincides with Vicat initial setting time, the rate of hydration and the rate of evaporation influence crack formation.

3. The rate of shrinkage varies for different admixtures when the relative humidity changes. This results in lignosulfonate

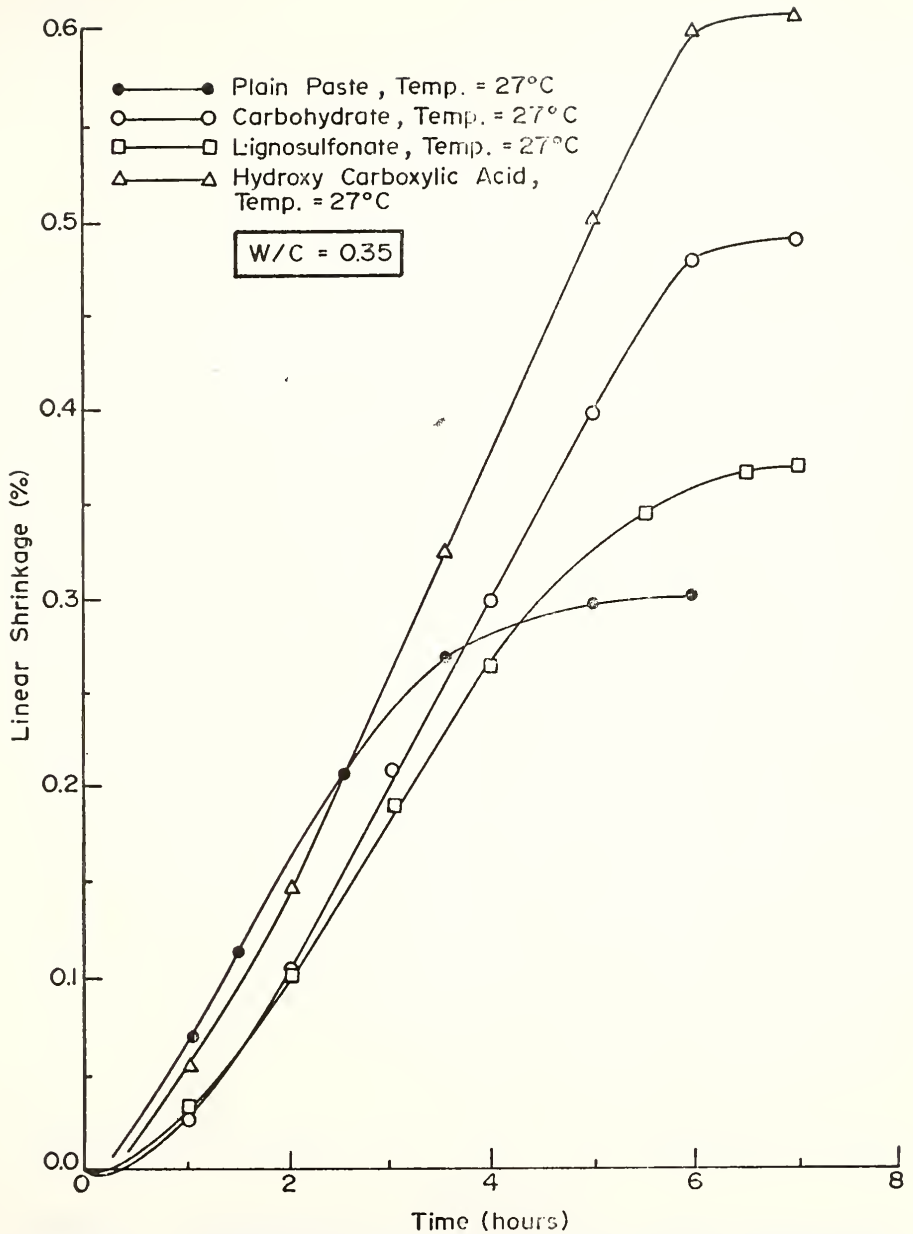


FIGURE 7 -COMPARISON OF SHRINKAGE AT 25% RELATIVE HUMIDITY.

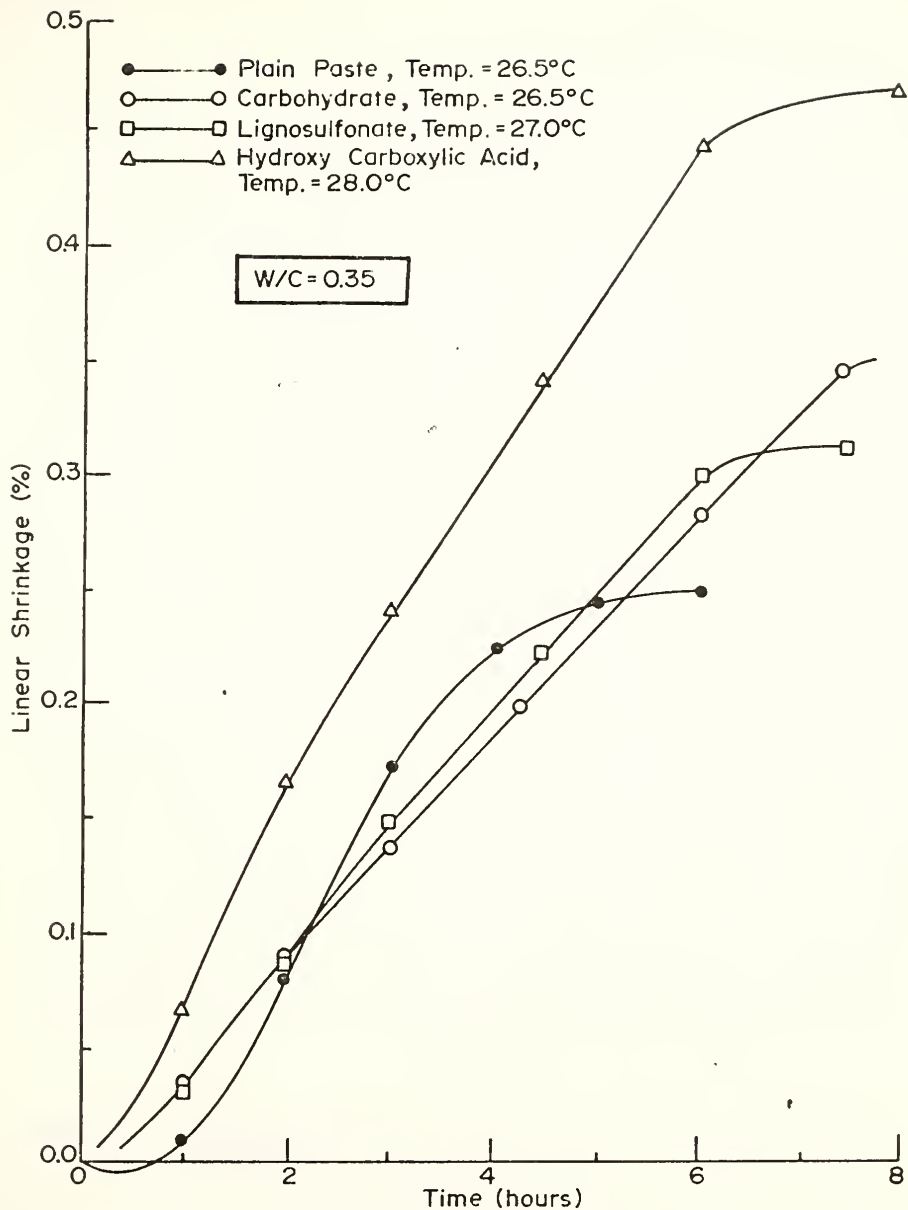


FIGURE 8 - COMPARISON OF SHRINKAGES AT 50% RELATIVE HUMIDITY.

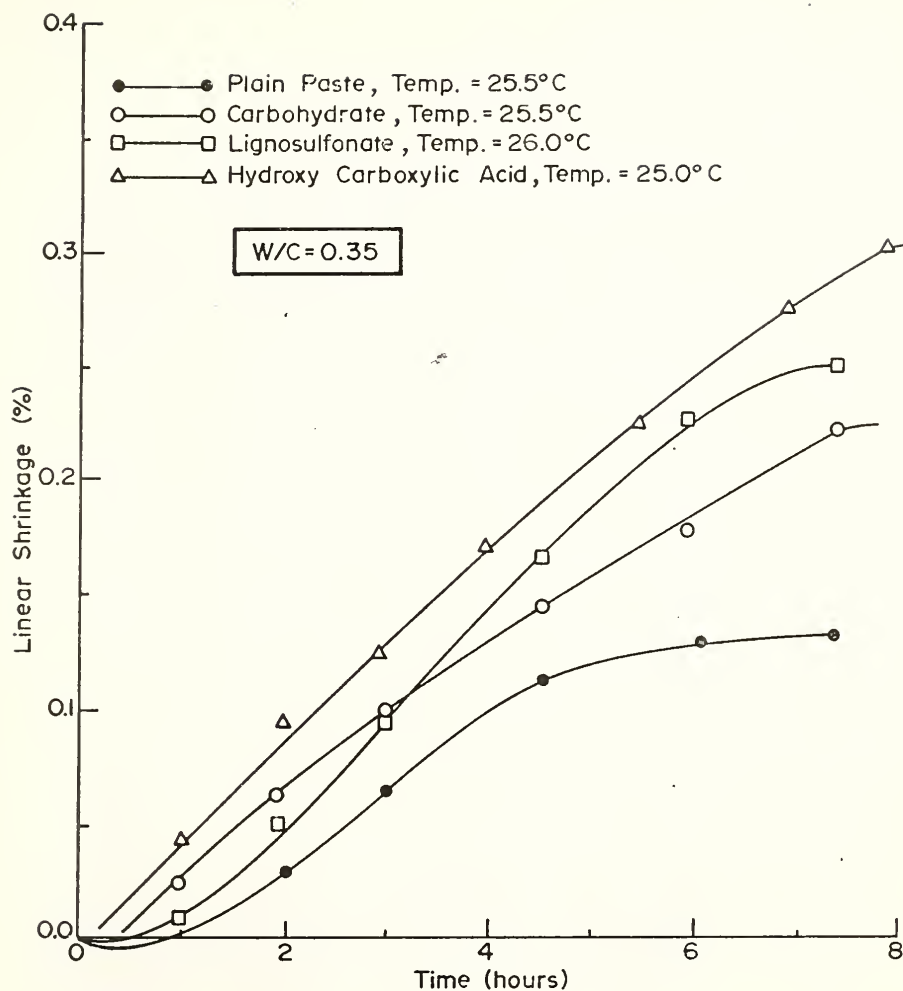


FIGURE 9 - COMPARISON OF SHRINKAGES AT 75% RELATIVE HUMIDITY.

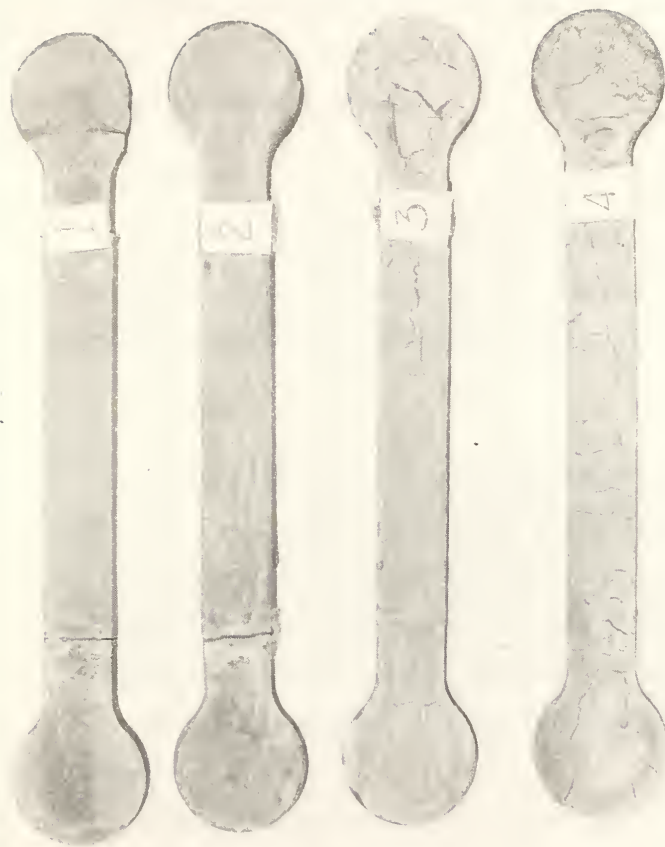


FIGURE 10 COMPARISON OF SPECIMENS AT 25% R.H.

- | | |
|-------------------------|---------------------------------|
| 1. Plain paste | 2. Using lignosulfonate |
| 3. Using carbonyhydrate | 4. Using hydroxycarboxylic acid |

giving the most uniform amount of shrinkage at different relative humidities.

4. The morphology of the plastic cement paste is apparently different for different admixtures are evidenced by difference in the bleeding and in rate of shrinkage.

C. Drying Shrinkage of Concrete

1. Admixtures.

The three commercially available admixtures used in the previously described portions of this research project were used as were some mixes of glycolic acid and plain sucrose.

2. Procedure.

Concrete was proportioned with a cement factor of 564 pounds per cubic yard (Type I cement), air entrainment varied between 3 and 5 percent and slumps were either a high (6 inch) or a low (2 inch) slump. All mixtures with retarders had a setting time, ASTM C 403, 50 percent greater than that of the unretarded concrete.

Two mix temperatures, 75°F and 55°F were used to evaluate temperature effects.

Shrinkage specimens were 3 x 3 x 10 inch prisms cast according to ASTM C-157 with the exception of the planned temperature variations.

Specimens were uniformly cured and length determination made at ages of 1 day, 7 days (when curing terminated), 14 days and 28 days, 3 months and 6 months.

3. Results.

Table 3 contains the results of the shrinkage tests. The differences are so small that it seemed fair to conclude that differences in drying shrinkage behavior of concretes with or without retarding admixtures are not great enough to be of significance in engineering considerations.

IV. SUMMARY OF RESULTS

This investigation considered many types of retarders and it is reasonable to assume that generalizations made about these probably apply to all retarders whether tested or not. The effectiveness of retarders varies greatly insofar as the concentrations required and in their effect on early hydration rates. Many strong retarders were found to accelerate the very early hydrations of cement which was measured by the length of time to reach a penetration of 50 psi - yet they retarded the set time to 500 psi (initial set).

Measurements of the surface area of various retarded pastes indicate variations in microstructure prior to 40 percent hydration. Drying shrinkage was also most variable at degree of hydration less than 50 percent.

The variability of early retarders performance is also shown in the work as plastic drying shrinkage. There considerable differences occurred with the different admixtures and with varying intensity under various drying conditions.

Table 3

DRYING SHRINKAGE RESULTS

Mix No.	Mix Temp.	Slump	Admix. *	Shrinkage, percent				
				7d	14d	28d	3mo	6mo
1	Room	Low	N	0.006	0.012	0.026	0.036	0.041
2	Room	High	N	0.001	0.012	0.025	0.037	0.045
3	Room	Low	L	0.003	0.015	0.033	0.041	0.050
4	Room	High	L	0.003	0.021	0.037	0.047	0.054
5	Room	Low	A	0.005	0.020	0.033	0.038	0.043
6	Room	High	A	0.003	0.018	0.032	0.039	0.042
7	Room	Low	C	0.006	0.027	0.038	0.046	0.054
8	Room	High	C	0.007	0.026	0.040	0.050	0.056
9	Room	High	G	0.002	0.016	0.026	0.044	0.054
10	Room	High	S	0.006	0.021	0.034	0.047	0.059
11	Room	Low	C	0.006	0.022	0.037	0.049	0.050
12	Room	High	L	0.001	0.020	0.034	0.052	0.054
13	Room	High	A	0.002	0.017	0.029	0.043	0.045
14	Room	High	L	0.003	0.025	0.037	0.051	0.050
15	Room	Low	C	0.004	---	0.038	0.053	0.050
16	Room	High	C	0.008	0.031	0.043	0.049	0.055
17	Room	Low	N	0.011	0.030	0.040	0.052	0.056
18	Room	High	N	0.010	0.026	0.036	0.049	0.054
19	Low	High	A	0.004	0.009	0.018	0.030	0.036
20	Low	High	C	0.003	0.022	0.030	0.042	0.047
21	Low	Low	N	0.019	0.030	0.036	0.052	0.062
22	Low	Low	N	0.001	0.015	0.026	0.034	0.054
23	Low	High	C	0.030	0.043	0.059	0.072	0.075
24	Low	High	L	0.002	0.020	0.035	0.046	0.054
25	Low	High	A	-0.004	0.009	0.021	0.032	0.036
26	Low	Low	L	-0.002	0.016	0.031	0.044	0.045
27	Room	High	G	0.012	0.020	0.030	0.042	0.047
28	Room	High	S	0.009	0.022	0.032	0.048	0.053

* N = No admixture, L = Lignosulfonate, A = Hydroxyacid,
C = Carbohydrate, G = Glycolic Acid, S = Sucrose

At the more fully hydrated conditions less drying shrinkage occurs and the results have a uniformity approaching those of the plain (no retarder) paste or concrete.

Plastic drying shrinkage was always increased by use of retarders because of the increased period of time in which the retarded specimens were in the plastic condition. Cracking of retarded paste specimens was greater than for the plain paste, however, visible differences did occur with the different retarders.

V. CONCLUSIONS

This investigation has shown that the various admixtures tested including those types in common use effect early hydration products albeit differently one from the other. A well-cured concrete which has a retarding admixture incorporated does not have enough increase in shrinkage to warrant concern. Likewise, the commercial types tested did not differ sufficiently to warrant any preference as to the type of retarders.

Shrinkage problems are more likely to develop with retarded concretes when severe drying conditions exist during placement resulting in more plastic drying shrinkage and cracking. Likewise poor curing may cause greater drying shrinkage of hardened concrete containing retarders. Shrinkage of concrete after more than 40 percent of the cement has hydrated was not significantly different than for plain concrete but at earlier ages retarders appear to significantly influence drying shrinkage.

From a practical viewpoint, good concrete curing practice is essential for concrete containing retarders but no new or additional steps should be required beyond those commonly required by the Indiana State Highway Commission or the agencies of other states.

COVER DESIGN BY ALDO GIORGINI